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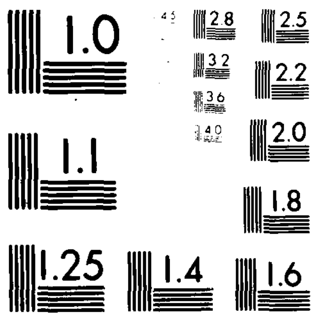

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REPORT NO. NADC-80097-60

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FLAME TESTING OF TWO SAMPLES OF EXPOSURE SUIT MATERIAL

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INTRODUCTION

Reported deficiencies in authorized quick-donning ship-abandon type exposure suits has prompted use of other suits made of materials with unknown flame and heat retardant properties. Therefore, tests were requested to be addressed first to the question of flammability of the material, and second to the question of heat retardation by the material. --> page 5

MATERIALS AND METHODS

In past flame-contact studies, this laboratory has established as limits total envelopment in flames for a 3-second period - "...three seconds as representative of the time for an uninjured man to run through 25 to 30 feet of flames, commensurate with the maximum exposure expected in a carrier deck crash fire," reference (a). Thus, in flame pit tests fully clothed manikins are moved through burning gasoline in 3 seconds at a rate of 10 ft/sec. Usually, bench studies of the fabrics are performed to determine whether their potential protective value merits fabrication into suits to be worn by manikins to be exposed in the fire pit. The apparatus used has been shown in detail, reference (b). It consists of a Meker burner and an automatically controlled carriage to carry the specimen into the flame and out again in a given period of time. The gas flow through the burner is controlled and the flame temperature monitored continuously. In the tests reported here, the heat flux through a circle 23 mm in diameter was thus maintained constant and closely reproducible for successive 3-second intervals. The materials under study were interposed between the lucite-mounted simulated skin and the carriage and clamped in place. The temperature rise at a point 0.5 mm below the surface of the skin simulant was measured by a copper-constantan thermocouple and recorded on an oscillographic chart moving at 5 mm/sec. (The oscillograph had been calibrated against a potentiometer.)

The ship-abandon type exposure suit was designed to meet the requirements of plane-ditching, sometimes associated with fire before impact. It could be expected that to effect a safe ditching, a pilot might sometimes be required to attend to his controls for more that 3 seconds during which he would be exposed to flames. The maximum tolerance time in such a case could probably best be determined by exposing the suit material for the time required to permit the temperature of the simulant to rise to 44 deg. C., the minimum level at which living skin is damaged, reference (a). From table I it can be seen that temperatures higher than 44 deg. C. can be tolerated by the simulants for a few seconds. However, injury is a function of the temperature/time integral of both the heating and cooling periods. Unless the endpoint was approached in many successively longer exposures, exceeding the critical temperature/time integral for injury was possible, expecially since temperature could not be read directly from the oscillograph chart. Furthermore, the curve traced by light on sensitive paper was not immediately visible. Insufficient material was available to allow this cautious, stepwise approach. Therefore, the material was exposed without backing by a simulant to determine whether it would be penetrated by the flame within a time in which it might be foreseen to be needed to shield a crewman's skin.

Two materials herein designated as M_2 and M_3 were submitted for testing. M_2 was identified as the material of which the "Imperial" suit is fashioned. It is a nylon-2 neoprene colored orange on the outside, blue on the inside, and "flesh-colored" between the layers of nylon. It was 4.90 mm thick, as nearly as so compressible a material could be measured, and weighed 1.343 kg/m^2. M_3 was identified as the material of the "Dancart" suit, also nylon-2 neoprene. The neoprene was black and separated an outer orange and an inner black layer of nylon. It too measured 4.90 mm in thickness and weighed 1.348 kg/m^2. The longer exposures were effected through a circular opening 31.75 mm in diameter, in a carriage carried into and out of the circa 1200 deg C (reference (C)) flame by manually activated solenoids at a speed that permitted the exposures to be considered rectangular. The exposures were timed with a stop watch.

Samples of M_2 and M_3 were exposed until the beginning of specific phase changes identified first in an anonymous sample of nylon-1 neoprene with the black nylon side toward the flame. The following phase changes in the material were observed:

1. Evagination toward the flame associated with apparent melting of the exposed side and adherence to the metal carriage.

2. Invagination of the exposed side away from the flame. This was apparently due to stretching of the unexposed side by the pressure of the burning gas or convection currents of air once the inner material had been incinerated and no longer acted as a pressure barrier and a cohesive force.

3. Porosity of the invagination tip apparently caused by stretch of the surface layer of neoprene permitting smoke to pass through it.

No flames perforated the invagination within 1 minute.

RESULTS

The temperature rise at a point 0.5 mm below the surface was measured in each of two skin simulants while protected by samples of each material. Thus it was intended that there should be a total of six exposures of each material. (However, M_3 was exposed only four times because the thermocouple of Simulant No 294 failed during its second exposure while protected by M_3, and insufficient material remained to repeat the tests of M_3 with a replacement simulant.) To normalize the temperature rises in the simulants for variations of $\pm$ 5% in the heat flux to which they were exposed, the temperature rises were expressed as deg C./cal/cm^2/sec. Each simulant was also exposed without protection four times. Averages of the results are shown in table I together with the time required for the peak temperatures to be reached. Peak temperatures were calculated on the assumption that even neoprene-clothed skin would not be warmer than 35 deg C. in a temperate environment before the exposure. It is obvious from the table that unprotected skin would be incinerated during a 3-second run through a carrier deck fuel fire, but that the M_2- and M_3-protected skins would warm no higher than normal rectal temperature. At such a skin temperature, a human subject would experience uncomfortable warmth, but not pain or injury.

Furthermore, a full minute (ample time in which to disrobe or be wetted down) elapsed before even these benign peak temperatures were reached.

Figure 1 is a comparison of M_2 and M_3 at the beginning of evagination toward the flame, which occurred together with smoking at 6 seconds in M_2, and at 8 seconds in M_3. The outer side of the material (the side toward the fire) is shown. Smoke from M_3 did not appear until after removal of M_3 from the fire, yet the damage to M_3 seems to be greater than to M_2.

Figure 2 compares the materials at the second phase change (beginning of invagination away from the flame and toward the skin). This phase change occurred at 19 seconds in M_2, and at 26 seconds in M_3. Depth of charring was circa 1.09 mm in M_2, and circa 2.16 mm in M_3. Furthermore, the charred material fell out of the M_3 sample and had to be scraped out of the M_2 sample.

Perhaps the time to beginning of these phase changes is meaningless or, at least, is too subjective an observation because the material that was noted to arrive at these phase changes later shows more damage. In the first test performed, M_2 showed no tendency to burst into flames after 3 minutes of exposure followed circa 20 seconds later by still another minute of exposure. The blue side shown in Figure 3 is the side that would be next to the wearer's skin. The outer edges clamped by the metal frame show melting of the blue nylon.

Figure 4 shows the outer exposed side of the same sample. Apparently, the charred material acted as a thermal barrier between the flame and the undamaged material.

Figure 5, M_3 on the right showed burning on the exposed side after 2 minutes of exposure to the flame. Combustion on the under side continued after removal from the burner. (The apparent permeability of the material to light is an "artistic" contribution by the photographer.) M_2 on the left was exposed again to determine whether it also would exhibit combustion on the exposed side within 2 minutes. At 1 min 50 sec, it perforated in this test and became engulfed in flame, which needed to be extinguished.

Figure 6 showed the side that would have been next to the skin. The black nylon of M_3 shows scorching that cannot be seen well in the photograph. Insufficient material was available to permit further tests by which the variable tolerance to exposure might have been explained.

DISCUSSION

It should be remembered that an air gap would exist between the skin and a suit made of these materials, whereas in the bench tests the material was clamped to the simulated skin. Therefore, the skin of the wearer probably would not reach even the benign peak temperatures reached in the bench tests. Returning again to the question of tolerance time, we could refer to the graph of Stoll and Chianta (reference (d) which relates the 3-second temperature rise in the simulant (not the maximum rise after a 3-second exposure) to tolerance

time to a heat flux of 1 cal/cm^2/sec. However, even in the worst cases in the present study of a 2.63 deg C. rise in 60 seconds, or a 2.36 deg rise in 48 seconds, the 3-second temperature rise was less than 0.1 deg. Their graph does not plot 3-second temperature rises smaller than 1.36 deg C. In that case, the time to pain is 10.5 sec. The graph can be extrapolated to 70 sec to pain for a 3-second temperature rise of 1 deg, and to nearly 1000 seconds for a rise of only 0.1 deg. Such an extrapolation would assume unchanged thermal conductivity of the material, but conductivity probably would increase rapidly as the material was incinerated, so that the empirical tolerance time might be fewer than 100 seconds. However, the temperature rise of 0.1 deg C. at 3-seconds can be compared with 5.3 deg C., the comparable temperature rise of the most protective of the fabrics studied by these authors, described as "Nomex Staple and Fairtex", weighing "10.7 oz/yd^2" (0.363 kg/m^2) and 1.4 mm thick.

It is conceivable that the slightly larger temperature rise in the simulants during M_3-protection rather than during M_2-protection could be shown to be statistically significant in a larger number of trials, but it is doubtful that the difference would be practically significant.

CONCLUSION

The materials tested may provide better protection against standard 3-second exposures to fuel fires than any fabrics previously tested in this laboratory. However, the protection falls off sharply as the exposure is continued.

TABLE I - PEAK TEMPERATURES IN SKIN SIMULANTS EXPOSED TO FLAME FOR 3 SECONDS WITH AND WITHOUT PROTECTION

Simulant No.	delta T (deg C.)	delta T/H (deg C./cal/cm^2/sec)	Peak T (deg C.)	Time Reached (sec)
		UNPROTECTED		
294	45.25	36.66	80.25	3.2
234	44.04	35.12	79.04	3.3
		M_2-PROTECTED		
294	2.01	1.58	37.01	70
234	2.26	1.84	37.26	61
		M_3-PROTECTED		
294	2.59	2.06	37.59	67
234	2.42	2.06	37.42	62

Minimum skin temperature for injury: 44 deg C.

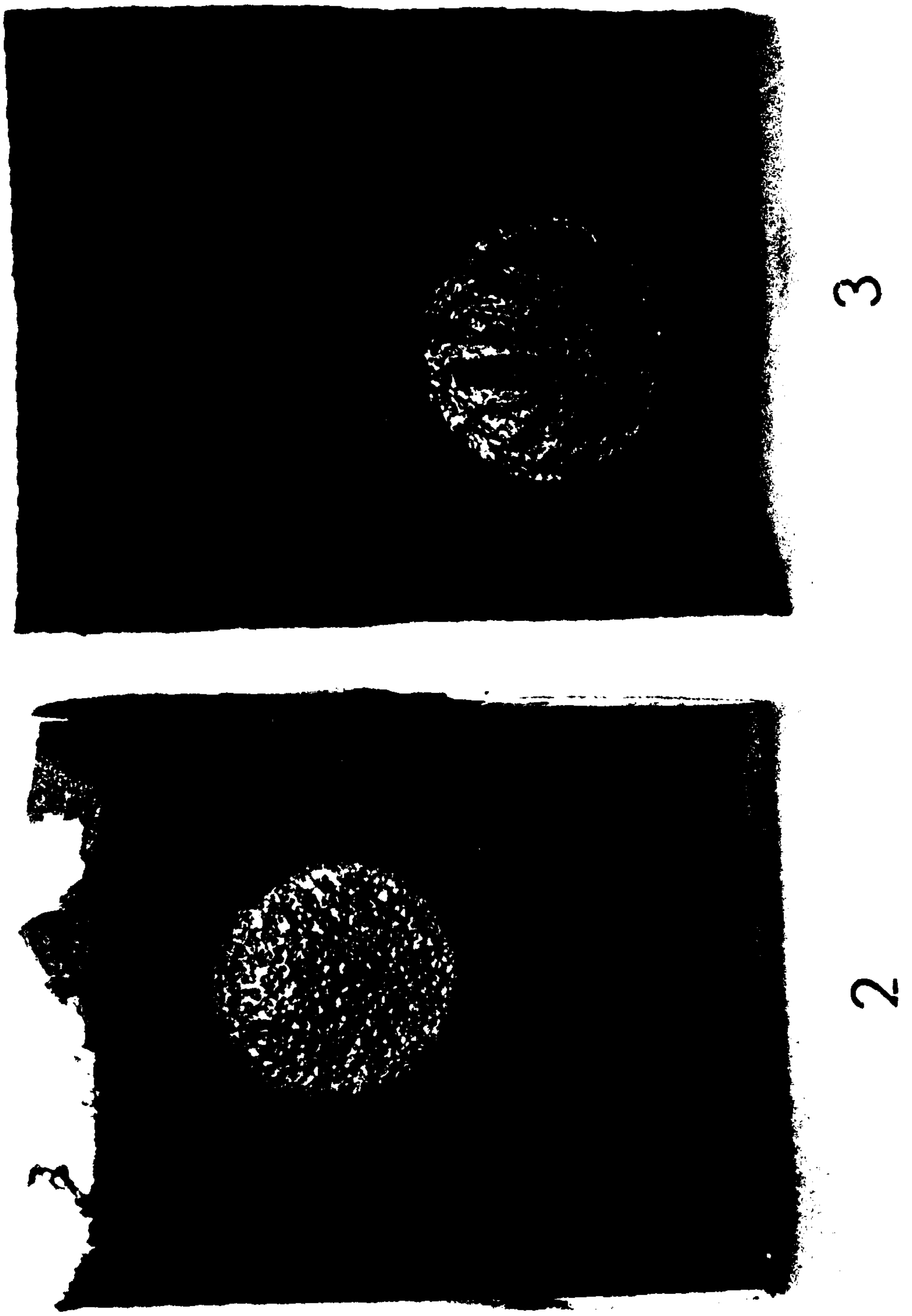

Figure 1 Out Side of the Materials at the Beginning of Evagination

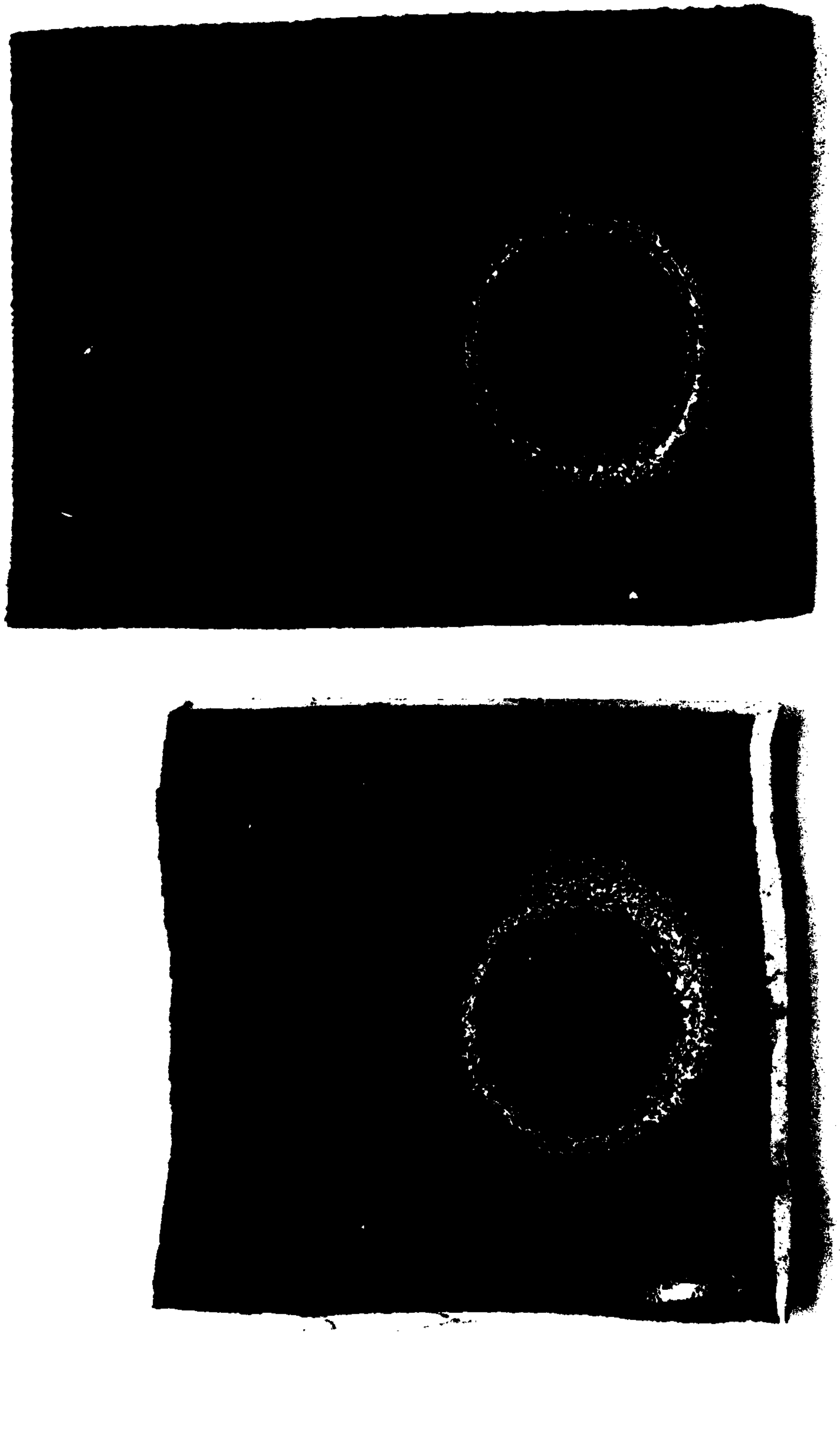

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Figure 2 - Outer Side of the Materials at the Beginning of Invagination

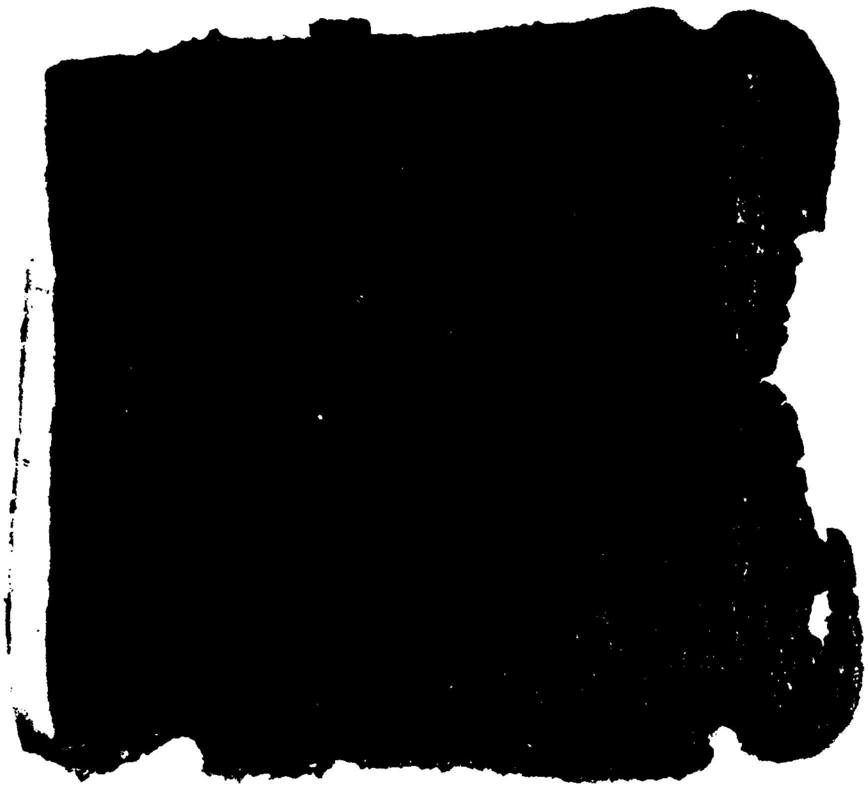

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Figure 3 - Inner Side of M_2 After Four Minutes of Exposure to Flame

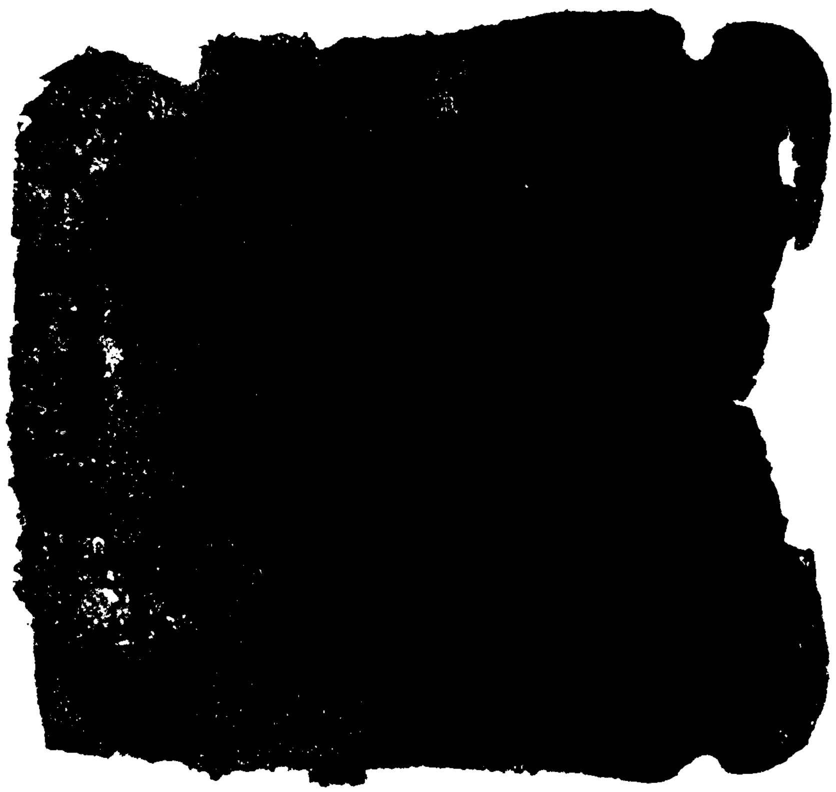

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Figure 1 - Outer Side of Mg After the Four minute Exposure

Figure 5 - Outer Side of the Materials After Two Minutes of Exposure

Figure 6 - Inner Side of the Samples Shown in Figure 5

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